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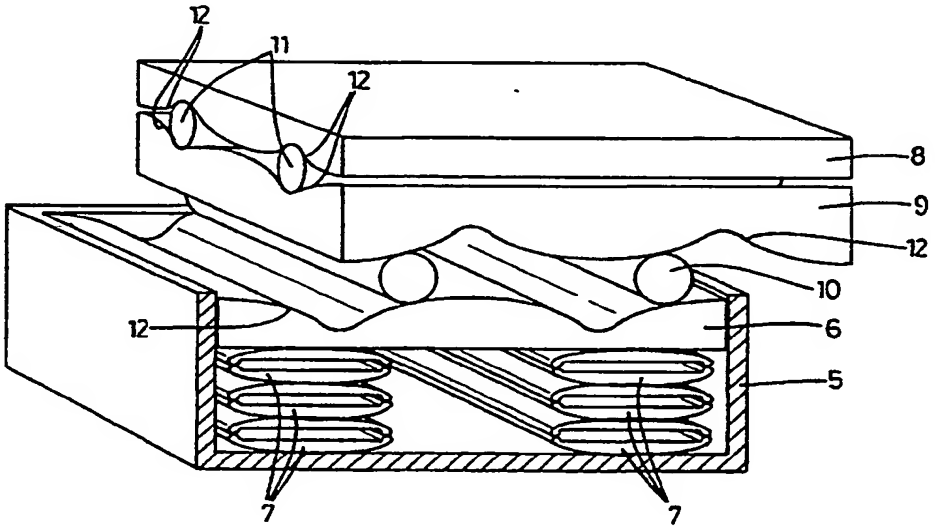

(57) Abstract

An apparatus for protecting structures, constructions and the like against earthquakes comprises at least a support having a bottom part (6), a top part (8) disposed above the bottom part and horizontally movable in relation thereto, on which the greater part of the structure rests, and a displacement mechanism disposed between the bottom and top parts (6, 8) allowing a controlled relative displacement of the bottom and top parts (6, 8), in such a way, that a relative horizontal displacement of the bottom and top parts (6, 8) causes a vertical displacement of one of said parts, which is counteracted by a resistance device (7). The displacement mechanism comprises a plurality of roller-shaped devices (10, 11), the shape of these devices (10, 11) and/or the top and/or bottom (6, 8) parts being such that a rolling movement of the roller-shaped devices (10, 11) from an intermediate position causes a vertical displacement of the part fitted with the resistance device (7).

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Apparatus for protecting structures, constructions and the like against earthquakes

The present invention relates to an apparatus for protecting structures, constructions and the like against earthquakes, comprising at least a support having a bottom part, a top part disposed above the bottom part and horizontally movable in relation thereto, on which the greater part of the structure rests, and a displacement mechanism disposed between the bottom and top parts, allowing a controlled relative displacement of the bottom and top parts, in such a way, that a relative horizontal displacement of the bottom and top parts causes a vertical displacement of one of said parts, which is counteracted by a resistance device.

Earthquakes cause constructional damage to structures in at least two ways. First, the horizontal movement of the ground, and hence of the foundation of the structure in relation to the structure itself, gives rise to damaging shear forces in the construction. These shear forces can crack concrete or stone, buckle vertical supports, and completely undermine the constructural integrity of the structure.

The second cause of damage to structures is the fact that the rhythmic movement of the ground during an earthquake can induce resonant oscillations of the structure. These resonant oscillations prolong and magnify the destructive effects of the earthquake and add to the damage to the structure.

The prior art is replete with examples of protective apparatus for buildings and other structures which are intended to minimize the effects of earthquakes. Many of these designs are ineffective in that they cannot prevent the two types of damage described above. For example, several types of supports comprising rubber blocks are known which, while reducing shear forces, present amplification tendencies, as a result of which the horizontal accelerations on the structure at worst are greater than those of the moving ground. Moreover, many

protective devices can be used only once and require repair or replacement after each earthquake, and are therefore impractical and uneconomical.

However, one effective protective apparatus is known from the US patent application no. 07/446.951 of the same inventor. This apparatus, on which the present invention is based, comprises a vertical displacement mechanism consisting of four legs fitted with knees. In the intermediate position, the knees of all four legs lean against the vertical inner wall of a housing. In the case of a lateral displacement of the interconnected upper ends of the legs, the knees of the legs extend and a spring at the lower end of the legs is compressed. As a result of this, the horizontal force, after having been converted into a vertical movement, is absorbed, which provides an effective protection for the supported structure.

The present invention aims to provide an apparatus of the type mentioned in the introduction, which is further simplified and which can be manufactured more economically.

To this end, the apparatus according to the invention is characterized in that the displacement mechanism comprises a plurality of roller-shaped devices, the shape of these devices and/or the top and/or the bottom part being such that a rolling movement of the roller-shaped devices from an intermediate position causes a vertical displacement of the part fitted with the resistance device.

The use of the roller-shaped devices, which allow a relative horizontal displacement of the top and bottom parts, permits a very compact construction in upward direction. In addition, the apparatus can be easily dimensioned for high loads, without this leading to an excessive increase in costs or unmanageable dimensions of the construction. For the sake of simplicity, the resistance devices may consist of mechanical springs, e.g. very strong Belleville springs. Because of the low number of movable parts, the risk of defects is very small, as a result of which the operation will be reliable.

Although, in principle, it is possible to use balls as roller-shaped devices, it is preferable according to the invention that the displacement mechanism comprises an intermediate part and that the roller-shaped devices consist of rollers which are disposed above and below the intermediate part, the rollers between the bottom and intermediate parts being placed essentially perpendicularly to the rollers between the top and intermediate parts.

The rollers confer a high load-bearing capacity to the apparatus, while each pair of rollers provides a stable support.

The vertical displacement could be realized by using rollers with an oval cross-section, but the most stable construction is obtained when circle-cylindrical roller-shaped devices are used, and when the top, intermediate and bottom parts comprise running surfaces with recesses in which the roller-shaped devices concerned are located in the intermediate position.

The invention will hereinafter be explained with reference to the drawings, which represent an embodiment of the apparatus according to the invention.

Figure 1 is a view of a bridge constituting the structure fitted with the embodiment of the apparatus according to the invention.

Figure 2 is an enlarged perspective and highly schematic view of detail II in Figure 1 which shows the apparatus according to the invention.

Figure 3a, 3b illustrate the operation of the apparatus according to the invention.

Figure 1 illustrates the incorporation of the supports 1 of the apparatus according to the invention in a bridge 2 which in this case constitutes the structure which is protected against earthquakes by the apparatus. It should be mentioned that the invention can also be used with various other types of structures, such as other public works and buildings and the like, and also with constructions, such as auxiliary generators, computer equipment, and other more or less vulnerable objects, e.g.

large works of art. In this case, the apparatus is installed at a high level of the piers 3 of the bridge 2, so that only the superstructure 4 is supported by the apparatus. It is of course also possible to place the supports 1 of the apparatus under the piers 3. For each particular case, the most favourable position can be chosen.

Figure 2 shows one of the supports 1. The support 1 comprises a housing 5, in which a plate-shaped bottom part 6 is incorporated, which is supported by the bottom of the housing 5 through very strong springs 7, which have to be strong enough to support the weight of the superstructure 4 jointly in all supports 1. The support 1 further comprises a plate-shaped top part 8 and an intermediate part 9. The intermediate part 9 rests on the bottom part 6 through two parallel horizontally placed circle-cylindric rollers 10, while the top part 8 rest on the intermediate part 9 through two similar rollers 11. The running or contact surfaces, through which the bottom part 6, the top part 8 and the intermediate part 9 are in contact with the rollers 10, 11, have longitudinal cavities 12 in which the rollers 10, 11 rest in a stable intermediate position, as is the case for the rollers 11 between the top part 8 and the intermediate part 9 in Figure 2. From this intermediate position, the intermediate part 9 can move in one direction essentially horizontally in relation to the bottom part 6 with the aid of the rollers 10 (see Figure 2), while the top part 8 can move perpendicularly thereto in relation to the intermediate part 9 with the aid of the rollers 11. As a result of this arrangement of the rollers 10, 11 the top part 8 can move in any horizontal direction in relation to the bottom part 6.

In the case of an earthquake, the ground, and hence each pier 3 and each housing 5, will rock in horizontal direction with great accelerations. Due to the great mass of the superstructure 4 of the bridge connected to the top part 8, this will resist accelerations. If the magnitude of the mass supported by the support 1 is g, then a maximum effort of 0.04 x g will be exerted on the

superstructure 4 in the rolling direction of the rollers 10 or 11 during the movement of the intermediate part 9 or the top part 8, as it can be assumed that the rolling resistance amounts to 4% of g. Along the diagonal, the horizontal effort will amount to $0.04\sqrt{2} \times g$.

In order to make sure that the rollers 10, 11 are forced back to an intermediate position, the cavities 12 are provided, also shown in Figure 3, the bottom parts of which gradually slope up in outward direction. When the rollers 10, 11 are forced out of the cavities 12 by a horizontal movement of the bottom part 6 or the intermediate part 9, a vertical movement has to take place between the bottom part 6 and the intermediate part 9, and between the intermediate part 9 and the top part 8, respectively. As the superstructure 4 of the bridge 2 will strongly resist elevation thereof, the bottom part 6 will move vertically downward instead, thereby compressing the underlying prestressed springs 7 (Figure 3b). Because of the rolling resistance between the rollers 10, 11 and the parts 6, 8, 9, the slopes of the cavities 12 have to be at least 4% in order to force the rollers 10, 11 back to their intermediate position. If the compressive stress of the selected Belleville springs 7 increases by 30% during the vertical movement of the part 6, the rolling resistance will amount to $0.04 \times (g + 0.3\ g) = 0.052 \times g$, and hence $0.04\sqrt{2} \times (g + 0.3\ g) = 0.0735 \times g$ diagonally. The acceleration of the mass of the superstructure 4 will therefore not exceed $0.0753 \times g$, irrespective of the intensity of the earthquake, which is a very low value, protecting the structure extremely well against damage caused by earthquakes. The apparatus according to the invention will not have any amplification tendencies, as the cavities 12 for the rollers 10, 11, in combination with the springs 7, have excellent damping properties.

The final form and dimensions of the apparatus according to the invention is of course dependent on the application concerned. The material used may also differ in each particular case; the rollers 10, 11 may, for example, consist of high-grade steel and the parts 6, 8, 9

of cast steel. In the represented case of a bridge, each support 1 may have a length and a width of 1 m x 1 m, while the height may amount to about 0.5 m (dependent on the springs). In this case, a relative displacement of the parts 6, 8, 9 could amount to 50 cm, while the maximum load is 250 tons for each support 1.

From the foregoing, it will be clear that the invention provides an apparatus for the protection of structures against earthquakes, which can be constructed in a very compact way and which is extremely effective. The apparatus further presents a remarkable simplicity. When less excessive loads are exerted on the structure, e.g. by traffic, storm or small earthquakes, the invention does not adversely affect the stability of the structure.

The invention is not limited to the embodiment represented in the drawings and described in the foregoing, which can be varied in various ways within the scope of the invention. It is, for example, conceivable that instead of rollers, balls are used which are placed directly between the top and bottom parts, and which are located in cavities in the top and bottom parts in the intermediate position which are rotation-symmetric in horizontal direction. In addition, the springs may be also disposed on the top part of the support or even internally of the intermediate part consisting of two horizontal portions. The springs may also be replaced by other mechanical or hydraulic springs or other types of springs. In addition, the rollers that are to perform the same movement may be interconnected by spacers which, while permitting a rolling movement, keep the rollers at the same distance. These spacers may simultaneously serve to increase the lateral stability of the apparatus in normal use, by engaging the rollers through a friction system having a high static friction and a considerably lower dynamic friction. This friction system may, for example, consist of a fixed ring attached to the spacer which is pressed by springs against an axially facing wall of the corresponding roller.

CLAIMS

1. An apparatus for the protection of structures, constructions and the like against earthquakes, comprising at least a support having a bottom part, a top part disposed above the bottom part and horizontally movable in relation thereto, on which the greater part of the structure rests, and a displacement mechanism disposed between the bottom and top parts, allowing a controlled relative displacement of the bottom and top parts, in such a way, that a relative horizontal displacement of the bottom and top parts causes a vertical displacement of one of said parts, which is counteracted by a resistance device, **characterized** in that, the displacement mechanism comprises a plurality of roller-shaped devices, the shape of these roller-shaped devices and/or the top and/or the bottom part being such that a rolling movement of the roller-shaped devices from an intermediate position causes a vertical displacement of the part fitted with the resistance device.

2. An apparatus according to claim 1, in which the displacement mechanism comprises an intermediate part and the roller-shaped devices consist of rollers which are disposed above and below the intermediate part, the rollers between the bottom and intermediate parts being placed essentially perpendicularly to the rollers between the top and intermediate parts.

3. An apparatus according to claim 1, in which the roller-shaped devices are circle-cylindric and the top, intermediate and bottom parts comprise running surfaces with cavities in which the roller-shaped devices concerned are located in the intermediate position.

4. An apparatus according to one of the preceding claims, in which spring devices are fitted below the bottom part or above the top part, functioning as resistance devices.

5. An apparatus according to claim 4, in which the spring devices consist of Belleville springs.

6. An apparatus according to one of the preceding claims, in which the top and bottom parts, and possibly the intermediate part, are plate-shaped.

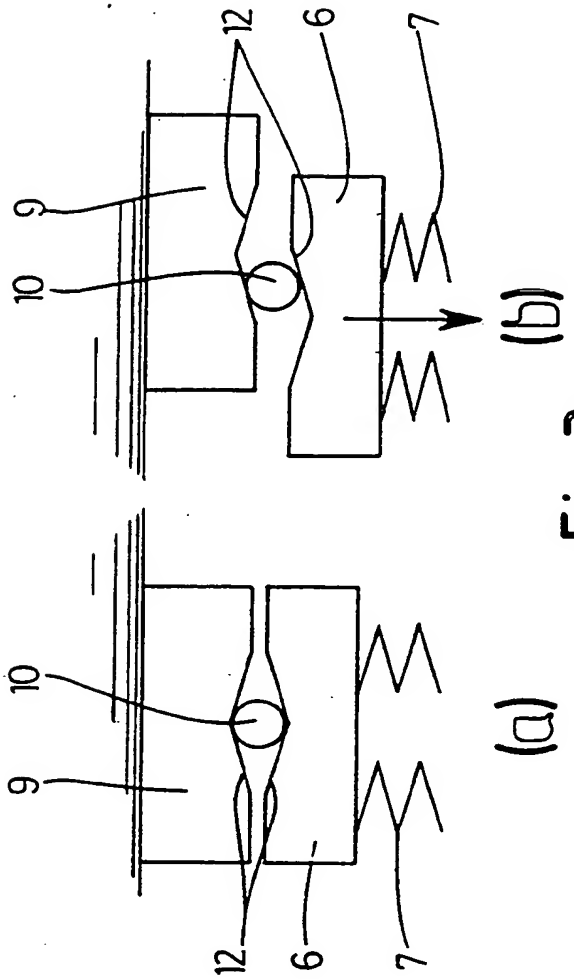

Fig.3

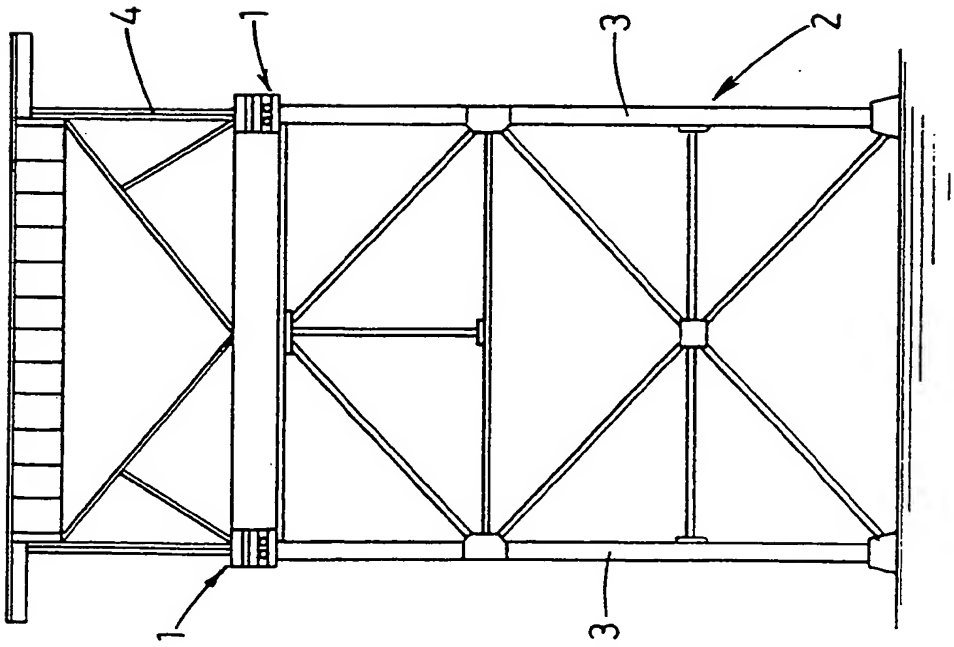

Fig.1

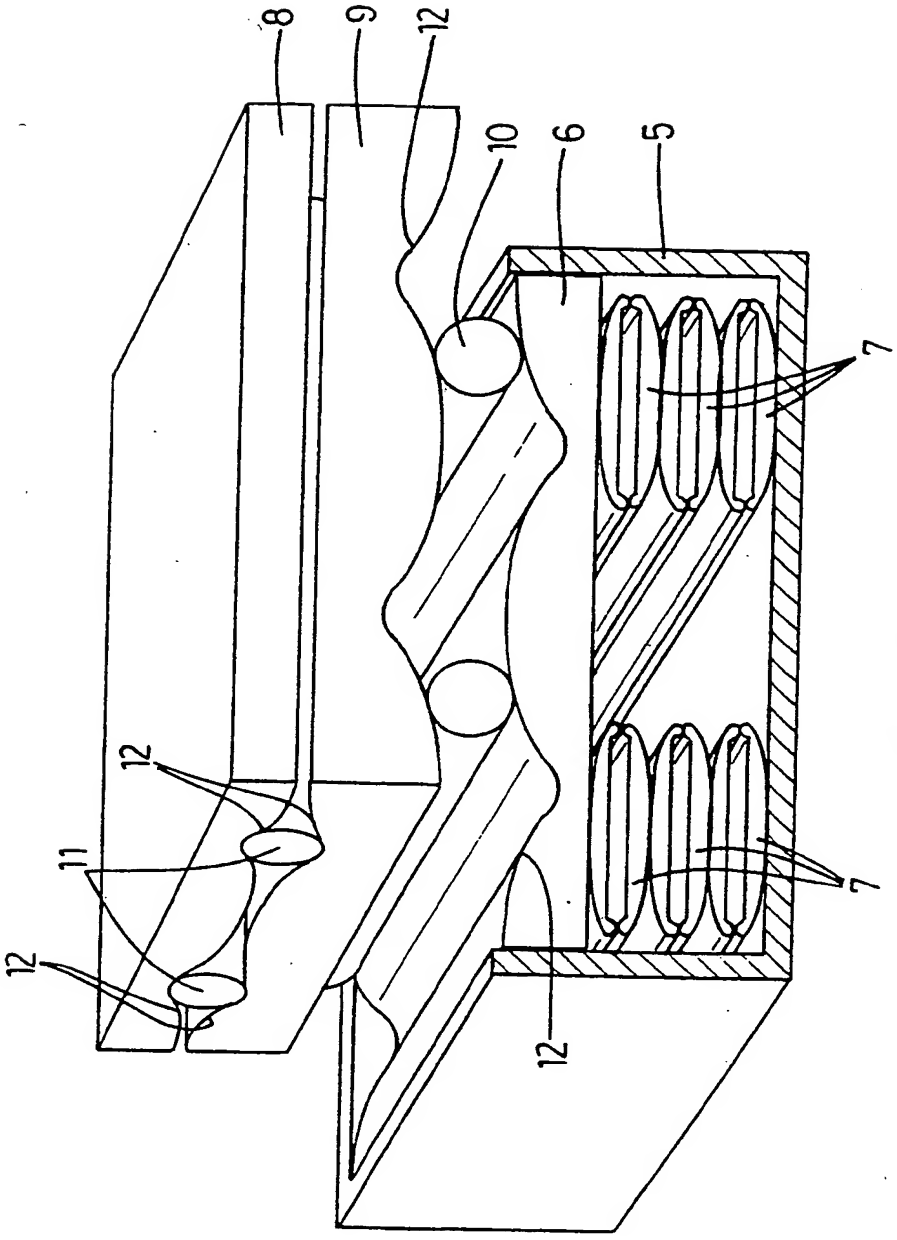

Fig.2

INTERNATIONAL SEARCH REPORT

Inter nal Application No
PCT/NL 95/00075

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 E04H9/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 E04H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	EP-A-0 072 869 (TOYAMA) 2 March 1983 see page 6, line 1 - page 8, line 3 see page 10, line 8 - line 27; figure 4 ---	1,4 2,3,5,6
X	PATENT ABSTRACTS OF JAPAN vol. 14 no. 13 (M-918) ,11 January 1990 & JP,A,12 060138 (EGAWA MINORU) 17 October 1989, see abstract ---	1
Y	EP-A-0 052 549 (FRAMATOME) 26 May 1982 see page 1, line 1 - line 5 see page 1, line 27 - page 2, line 20 see page 5, line 1 - line 31 see page 3, line 9 - page 4, line 10; figures 1,2 --- -/--	2,3,6

[X] Further documents are listed in the continuation of box C.

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Date of the actual completion of the international search	Date of mailing of the international search report
22 June 1995	14. 07. 95

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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A	EP-A-0 439 272 (SUMITOMO GOMU KOGYO KABUSHI KAISHA) 31 July 1991 see column 10, line 49 - column 11, line 44 see column 9, line 25 - line 35 see column 12, line 30 - column 13, line 9; figures 9,14,17	1-4,6
A	US-A-5 081 806 (POMMELET) 21 January 1992 see column 3, line 20 - line 64 see column 5, line 29 - line 61; figures 2-6,10,11	1,5
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INTERNATIONAL SEARCH REPORT

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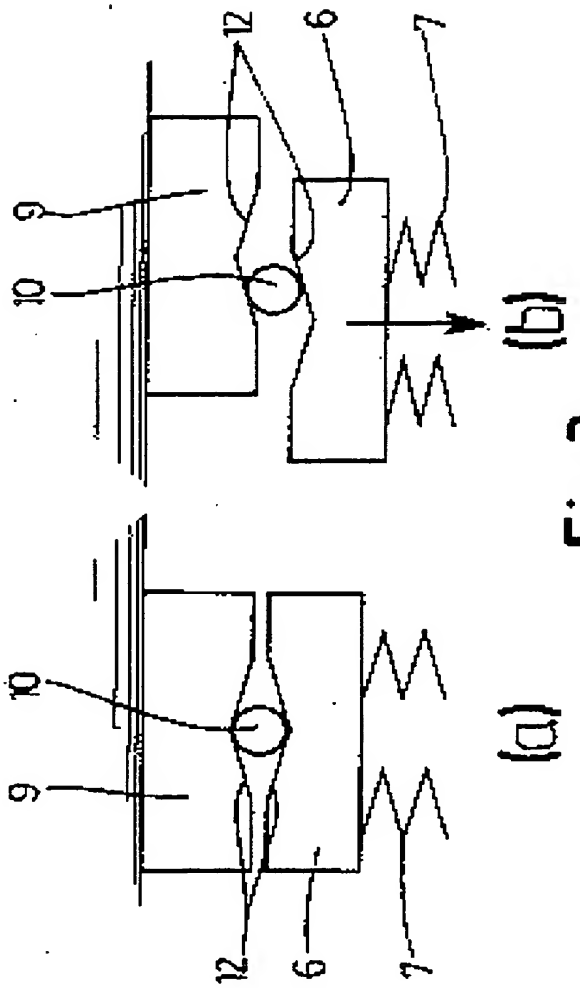

Fig.3

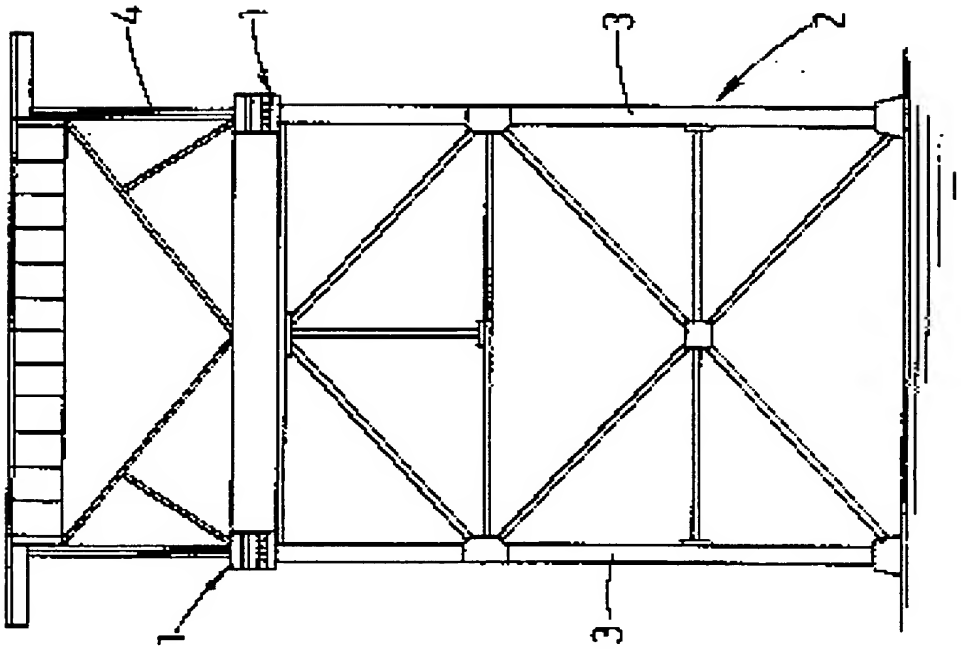

Fig.1

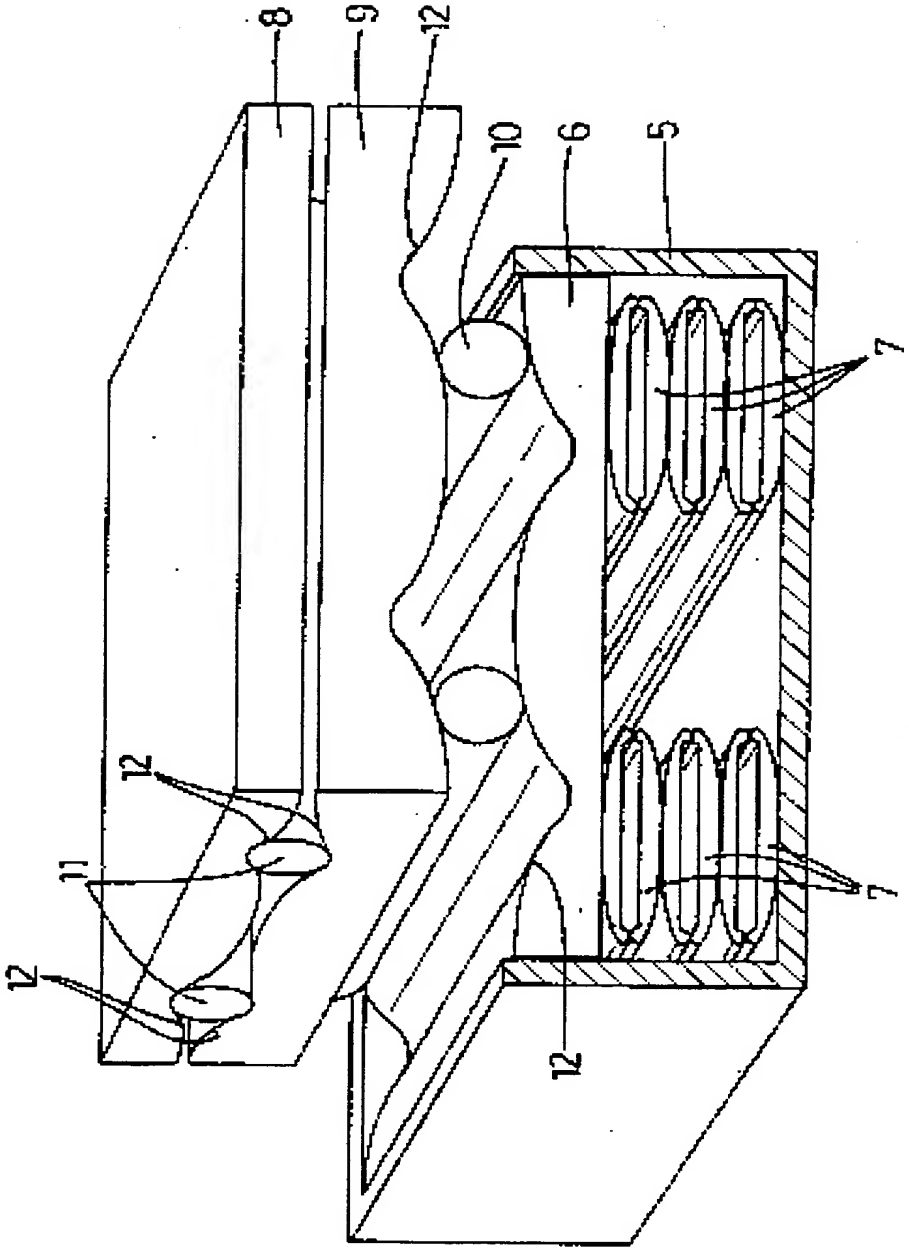

Fig.2